

AEROTHERMAL MODELING PROGRAM--PHASE II***ELEMENT B: FLOW INTERACTION EXPERIMENT**

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INTRODUCTION

This research is conducted as part of the NASA Lewis Research Center program to improve the design process and enhance the efficiency, life, and maintenance costs of the turbine engine hot section. Recently, there has been much emphasis on the need for improved numerical codes for the design of efficient combustors. For the development of improved computational codes, there is a need for an experimentally obtained data base to be used as test cases for the accuracy of the computations.

The purpose of Element-B is to establish a benchmark quality velocity and scalar measurements of the flow interaction of circular jets with swirling flow typical of that in the dome region of annular combustor. In addition to the detailed experimental effort, extensive computations of the swirling flows are to be compared with the measurements for the purpose of assessing the accuracy of current and advanced turbulence and scalar transport models.

The Allison program for Element B has five major tasks:

1. Experimental Configuration
2. Modeling
3. Measurements
4. Results and Analysis
5. Model Improvement

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EXPERIMENTAL CONFIGURATION

This task involved preliminary design of the test section, its detailed design for fabrication and the experimental plan for data acquisition. The test section is of rectangular cross-section (15 in. x 3 in.) and extends 10 duct heights (30 in.) downstream from the head plate (Figure 1). The test section is constructed of glass and plexiglass to facilitate optical access for the laser Doppler velocimeter (LDV). The main flow is established using five swirlers and the primary jets are injected in cross-flow. Each swirler consists of an actual swirler from the production of the Allison 570-K turboshaft gas turbine engine. These are 60 degree angle flat vane swirlers with 12 vanes. They have an outer flow diameter of 1.459 in. and inner flow diameter of 1.084 in. The center swirler region is that of interest for taking data. The two swirlers on either side of the center are to remove side-wall effects inherent to the model but not in an actual combustor. Under this task, two similar rigs - one using air for LDV measurements, and the other using water for flow visualization have been designed. The detailed test matrix for the flow interaction program is given in Table 1 and the corresponding flow configurations are shown in Figure 2. These tests are designed to determine the effect of jet downstream location, number of jets, mass flow, and position relative to the swirl axis.

MODELING

A three dimensional code (COM3D) using the current turbulence model ($k-\epsilon$) was employed to simulate different flow configurations for a preliminary study of the flow fields. The primary objective of the task has been in highlighting different flow regions in the flow field that would be taken into account during LDV measurements so as to resolve these regions of steep velocity gradient. Results indicate that these configurations offer interesting flow fields for the final verification/validation of models against the data base. The predicted results were qualitatively reasonable and the interaction of the jets and swirling flow was clearly seen.

MEASUREMENTS

Under Task 3, two test rigs and various test configurations have been fabricated and assembled. Initial check out runs have been made to ensure that the rig, instrumentation, and data reduction software are performing well. For the flow configurations identified in Task 1, measurements will be made to obtain the following:

- o detailed wall static pressure distribution
- o mean velocity and Reynolds stress components using two-color, two-component LDV system
- o fluctuating and mean concentration measurements for assessing scalar transport models.

In doing some flow visualization, it was later discovered that there are two exit flow regimes. These are shown in Figures 3-5. At low mass flow rates, the exit flow expands outward at an angle considerably less than 90 degrees, and is not attached to the head plate. At high mass flow rates, the exit flow remains attached to the head plate all the way out to the side wall. With moderate flow rates, a bistable flow situation is set up. That is, the flow will oscillate between the two regimes. Detailed velocity measurements are underway and some of the results will be presented during the meeting.

RESULTS AND ANALYSIS

Measurements of velocity and smoke concentration will be analyzed to determine the probability density function and auto- and cross-correlations .

MODEL IMPROVEMENT

Due to limited success with the standard $k-\epsilon$ model and its modifications, work must continue in improving advanced turbulence and scalar transport models.

Turbulent closure of the mean flow equations is obtained by adopting a non-equilibrium and an equilibrium model for the Reynolds stresses using different pressure-strain models (ref. 1). In addition, performance of a high and a low Reynolds number model for combustor flow calculations using Reynolds-stress closures is investigated (ref.2-3). As for the turbulent scalar flux calculations, two different models are presented (ref. 3). One solves the algebraic equations for the scalar fluxes, while the other employs the transport equations for their respective scalar fluxes. The accuracy of the model is determined by comparing the results with measurements.

REFERENCES

1. Nikjooy, M., So, R. M. C. and Hwang, B. C., "A Comparison of Three Algebraic Stress Closures for Combustor Flow Calculations," ASME -85-WA/EE-3.
2. Nikjooy, M., So, R. M. C., and Peck, R. E., "Modeling of Jet - and Swirl - Stabilized Reacting Flows In Axisymmetric Combustors," ASME - Winter Annual Meeting, 1986.
3. Nikjooy, M., "On the Modeling of Non-reactive and Reactive Turbulent Combustor Flows," Ph.D. Thesis, Arizona State University, 1986.

TABLE 1
TEST MATRIX

Test No.	Configuration	ϵ_j/H	X_j/H	N_j/H_s	Tracer	Jets/Swirler
1	BC1	-	-	-	NO	-
2	BC2	-	-	-	NO	-
3	A	1.0	0.5	0.75	NO	2
4	B	1.0	0.5	0.75	NO	2
5	C	1.0	0.5	0.75	NO	2
6	D	1.0	0.5	0.75	NO	2
7	E	0.5	0.5	1.50	NO	4
8	F	0.5	0.5	1.50	NO	4
9	A	1.0	1.0	0.75	NO	2
10	B	1.0	1.0	0.75	NO	2
11	E	0.5	1.0	1.50	NO	4
12	F	0.5	1.0	1.50	NO	4
13	A	1.0	0.5	1.50	NO	2
14	A	1.0	0.5	0.75	YES	2
15	B	1.0	0.5	0.75	YES	2
16	E	0.5	0.5	1.50	YES	4
17	F	0.5	0.5	1.50	YES	4

TEST SECTION GEOMETRY

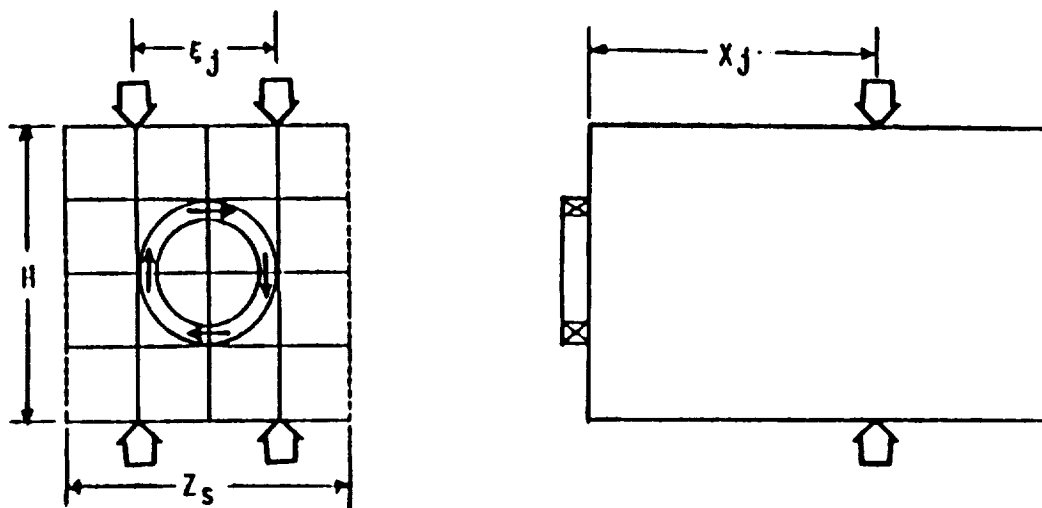
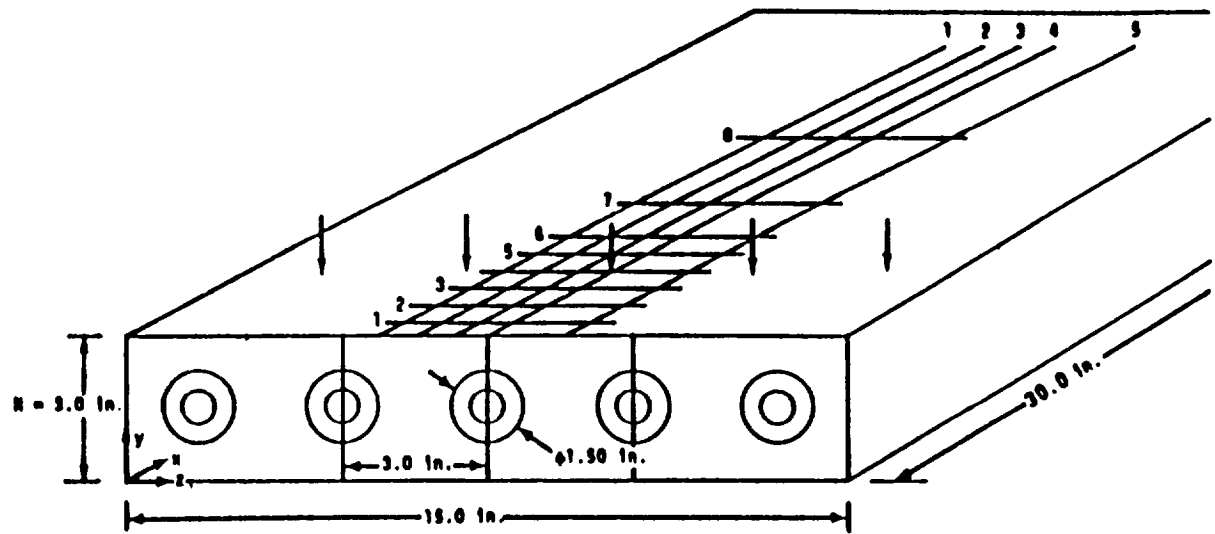
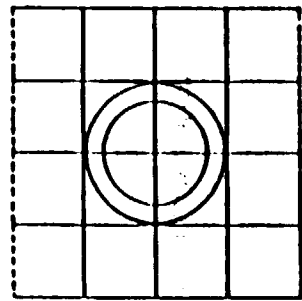
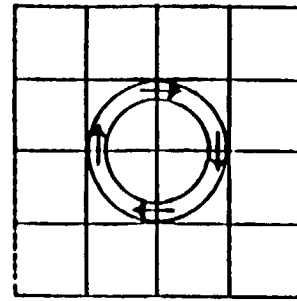


FIGURE 1

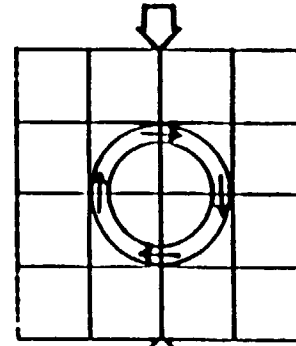
FLOW CONFIGURATIONS



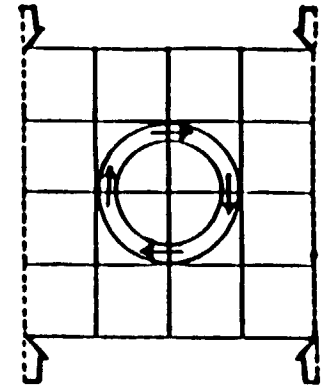
BASELINE CASE 1
(BC1)



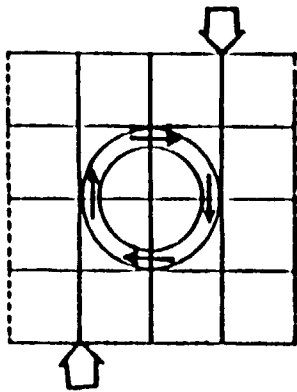
BASELINE CASE 2
(BC2)



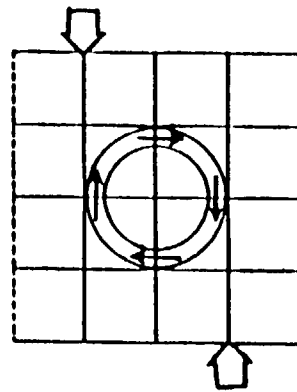
(A)



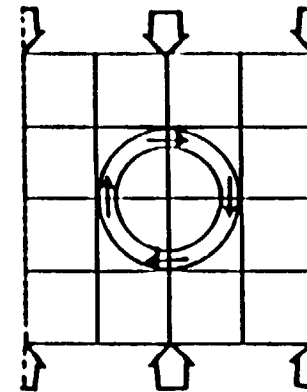
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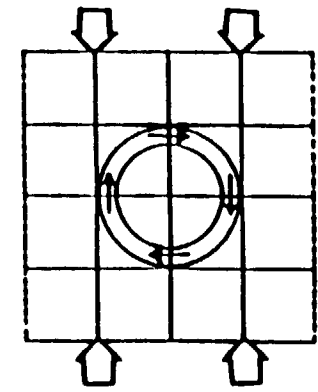
(C)



(D)



(E)



(F)

FIGURE 2

CONCENTRATION MEASUREMENTS (LOW REYNOLDS NUMBER)

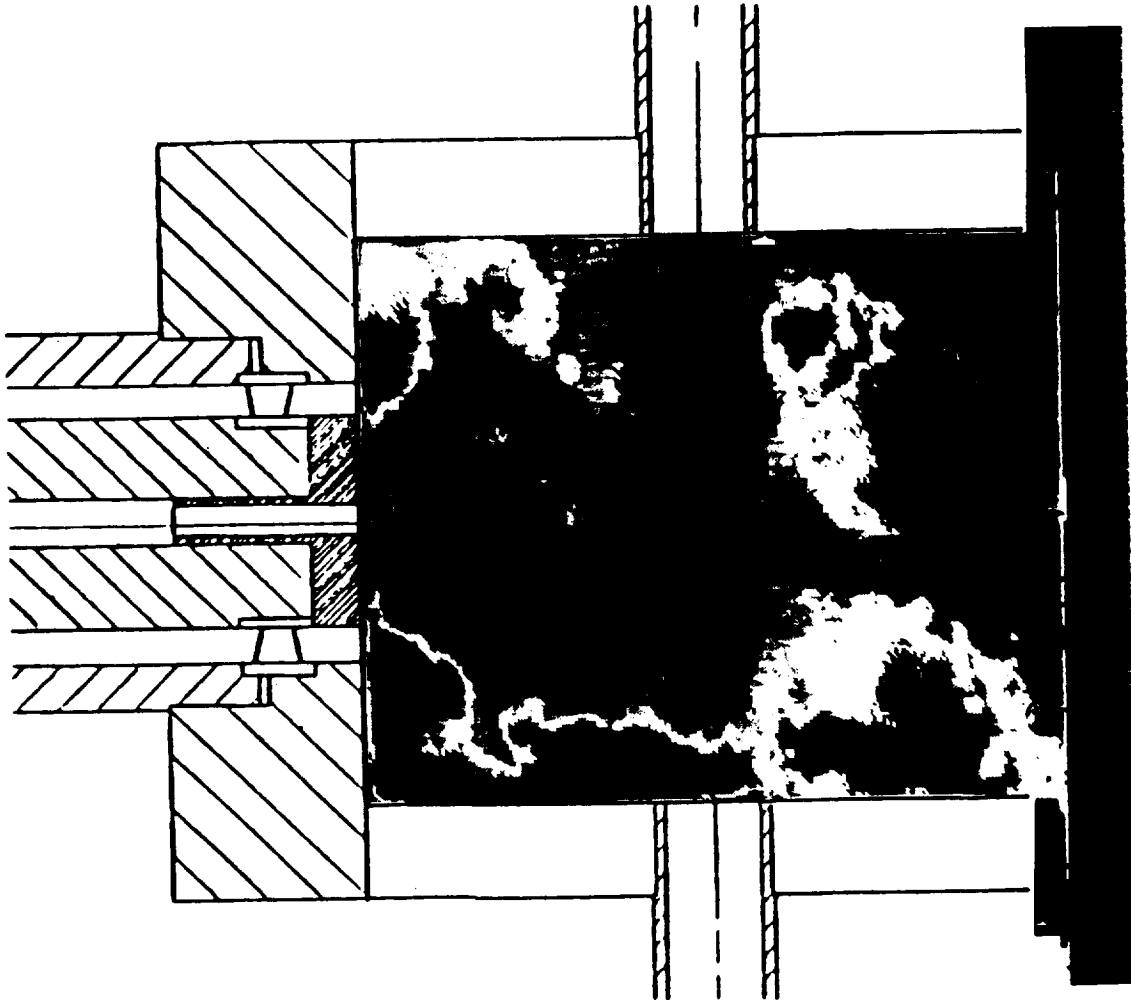


FIGURE 3

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CONCENTRATION MEASUREMENTS (HIGH REYNOLDS NUMBER)

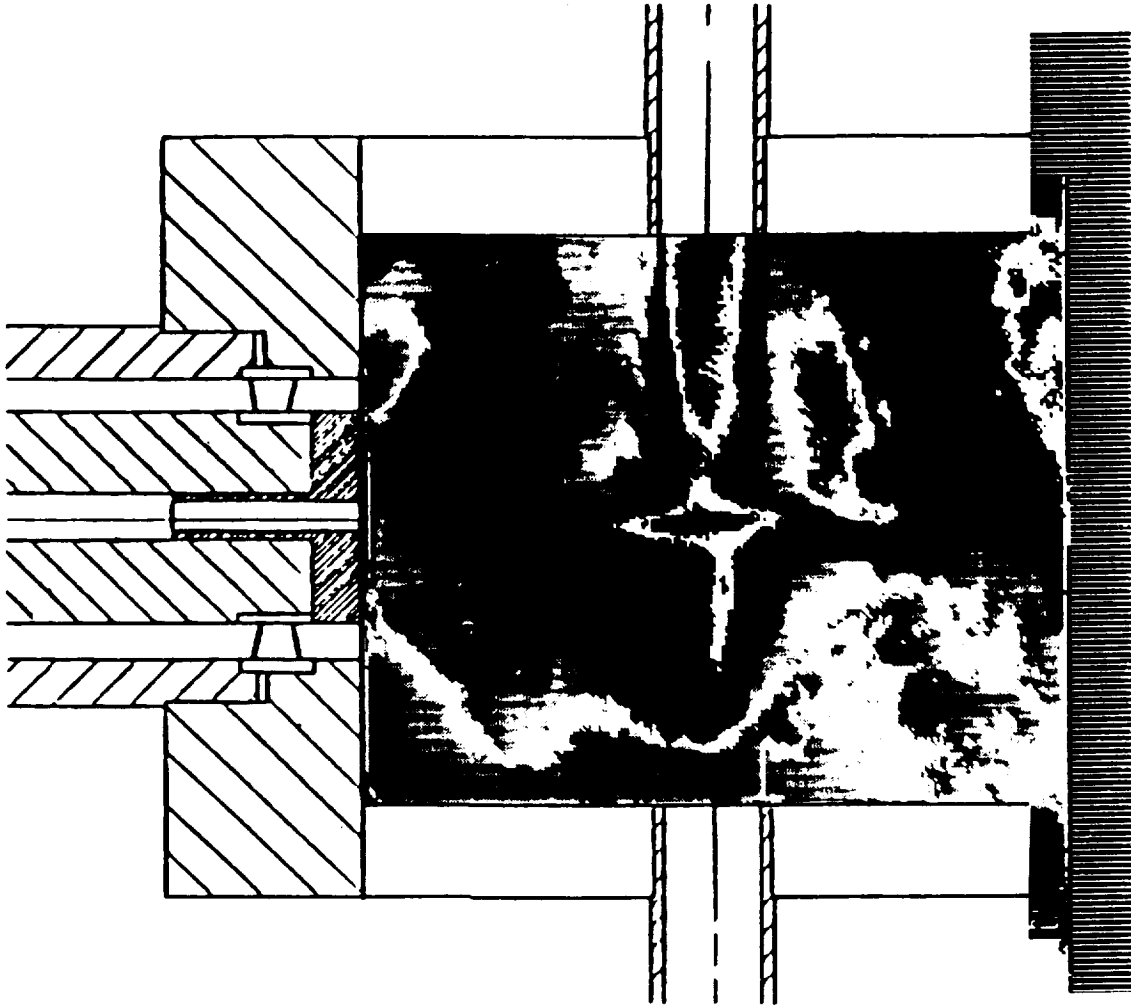


FIGURE 4

CONCENTRATION MEASUREMENTS (BISTABLE FLOW SITUATION)

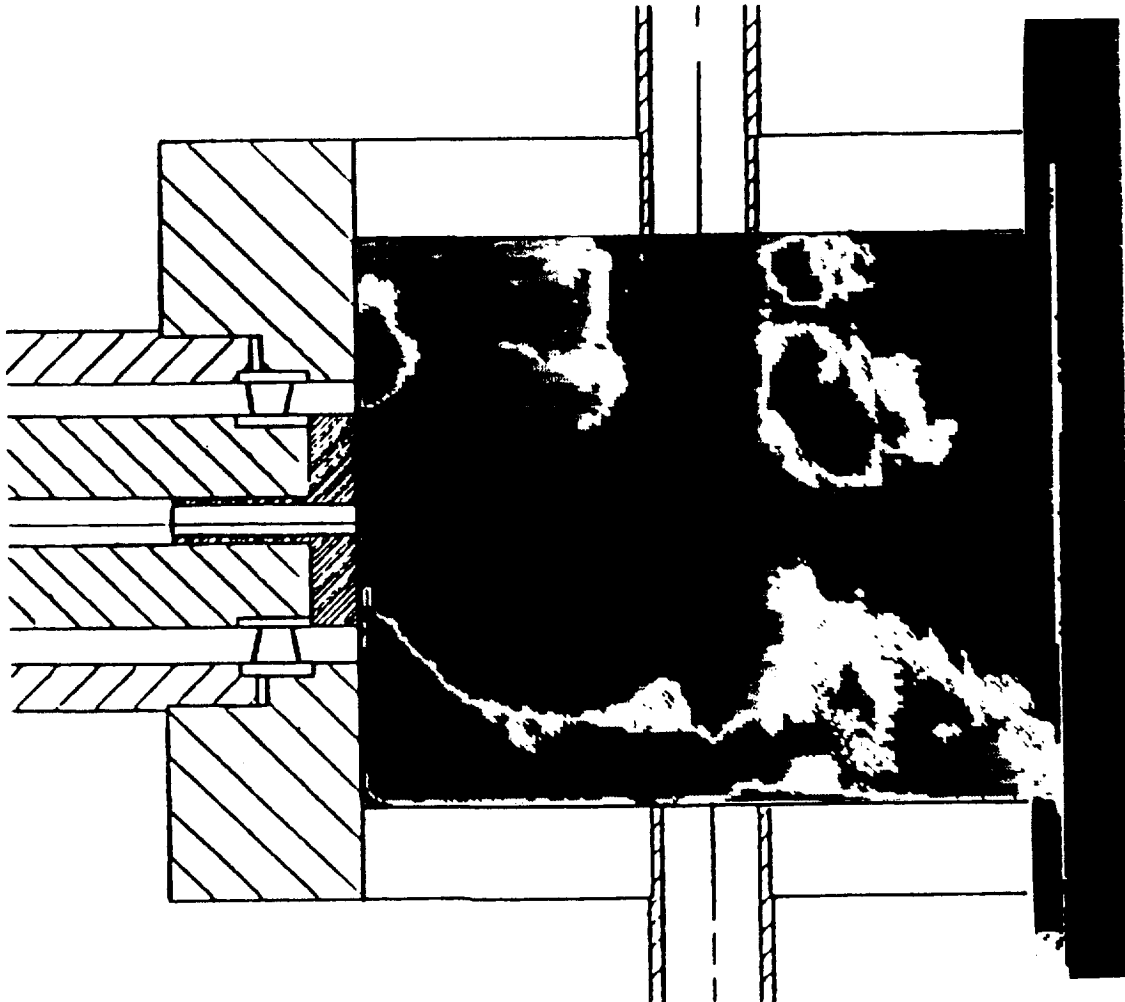


FIGURE 5